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Construction of a Concrete Arch

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CONSTRUCTION
OF A
CONCRETE ARCH

...BY...

Andrew Peder Munsen

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1904

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ANDREW PEDER MUNSEN

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering

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Construction of a Concrete Arch.

Introduction

Having been employed during the past summer by the Illinois Central Railroad in the construction of a sixty-foot concrete arch, I decided to take as my thesis a detailed description of the progress of that work.

The Illinois Central Railroad in double tracking its line from Fulton, Ky., to Memphis, Tenn., found it desireable to replace many of its single track pile trestles - of which there is a large number on this piece of road - with double track structures of a more permanent character; and consequently wherever conditions are suitable concrete structures are taking the place of pile trestles.

At Hatcher creek, 31 miles north of Memphis, a pile trestle was replaced by a sixty-foot semi-circular concrete arch.

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The trestle was of eleven bents, each about 14 feet long; and the greatest depth from base of rail to the bed of the stream was about 42 feet. Work was begun in May, 1903, and the arch was completed about Nov. 1, the same year. The trestle was built four years previous, when grade reduction was in progress on this part of the road, and was still in fair condition.

PART. I.

Foundations

Previous to beginning the construction of the arch, borings were made at both abutments, to a depth of about 30 feet below the bed of the stream. At that depth a hard red clay and gravel intermingled was encountered. This was overlaid by a strata of coarse sand about 2 feet thick and that by a layer of rather hard yellow clay 7 feet thick. Resting on this clay was a blue clay, which was so

plastic that the piles sank into it from 1 to 2 feet by their own weight. This blue clay continued to within a couple of feet below the bed of the creek. The upper 2 feet consisted of a dark blue alluvial soil or mud. The foundation was started at about 3 feet below the bed of the stream, or at 46 feet below the base of the rail. This allows about 3 feet for scour, an amount apparently sufficient, since the stream has shallow banks and is quite small except during floods.

The footing, 5 feet thick, rests on piles driven to an average depth of 23 feet below the bottom of the foundation, or about 27 feet below the bed of the stream. The borings it will be noticed, indicate that the piles at this depth would find nothing more difficult of penetration than a medium hard clay; but it was evident from observations in driving

that the last foot was through material very much harder than clay, proably a strata of coarse sand or gravel. In the foundation for the body of the abutment the piles were spaced 3 feet in rows and the rows were 3 feet apart. The spacing in the wings was variable and increased towards the tips. The piles were cut off 2 feet above the bottom of the footing, leaving 2 feet embedded in the concrete to form a strong bond and to prevent sliding.

Table 1 gives the calculated loading and the safe bearing power of the piles as figured by the Engineering News formula. The weight of the hammer was 2500 pounds.

Table 1.

No. of piles used in calculation	Average hammer fall Ft.	Av. penetration last blow. Inc.	Av. safe bearing power. Pounds.
8	22.0	1.00	53,300
10	19.8	1.10	47,600
12	20.6	0.91	54,000
Average	20.8	1.02	51,600

Safe bearing power of 196 piles in both foundations	9,900,000 lbs.
Safe bearing power of 8650 sq. ft. of plastic clay, well confined	5,180,000 "
Total safe bearing power	15,080,000 lbs.

Weight of 1,650 cu. yds. of concrete @ 4,050 lbs per cu. yd.	6,680,000 lbs.
Weight of 1,820 cu. yds. of earth spandral filling @ 2700 lbs per cu. yd.	4,900,000 "
848 ft. of live load @ 5000 lbs. per lin. ft. of track	850,000 "
Total load upon foundation	12,430,000 lbs.
Additional margin for safety	2,650,000 lbs.

This margin of safety is ample against future settlement, and is still further increased by the fact that a part of the load on the body of the footings will be destributed to the wings by the beam action of the concrete.

Cofferdams.

The cofferdams were started when the excavation had reached a point on a level

with the surface of the water in the creek. They consisted of a framework of 6"x8" walings and braces, built directly in place. Each cofferdam consisted of two frames. The upper one rested on posts 6"x8" 3 feet 6 inches long which in turn were supported by the lower frame, as shown in Fig. 1. Notice that the post supports both the horizontal brace and the waling piece. This was essential as the weight of the pile driver was later to be carried by the cross braces. The horizontal braces across the dam were spaced 6 feet apart, and were 19 feet 6 inches long through the body of the footing.

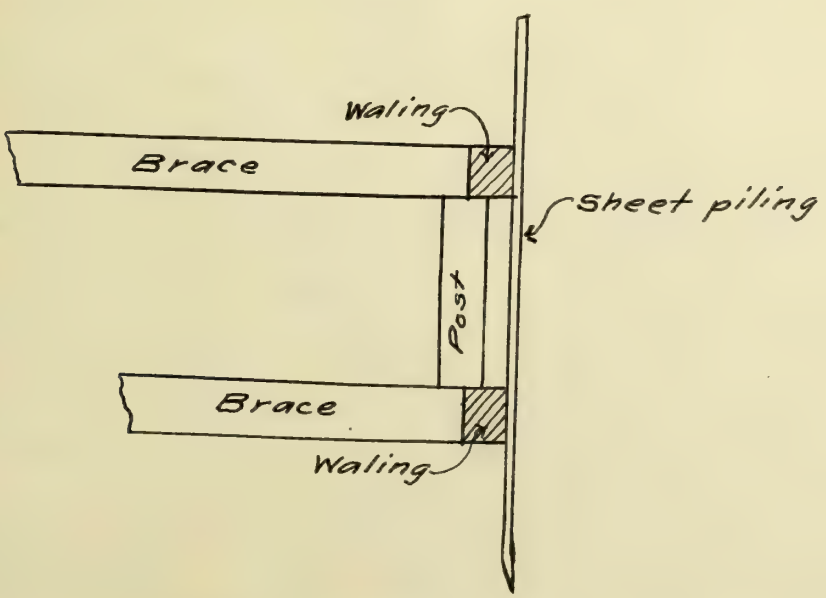


Fig. 1. Cofferdam Timbers.

around the frames 2"x8" tongued and grooved sheet piling 14 feet long was driven. As the excavating progressed the frames, together with the sheet piling, were sunk by driving with a sledge. After sinking about 5 feet in this manner the pressure against the sides made it impossible to drive the frames further; but by driving the sheet piling alone the excavation was carried down about 2 feet more, when a third frame was put in. By further driving the sheet piling the excavation was completed to the required depth - about 8½ feet below the surface of the water in the creek.

Very little trouble was experienced from leakage. Only such an amount of water entered the cofferdam during the night as two men using a diaphragm pump could easily remove in one hour each morning. Several times, however, both cofferdams were entirely flooded due to heavy showers raising the water in the creek until it flooded in

over the top of the sheet piling.

A good illustration of the old maxim, "save the penny and lose the dollar", forced itself upon the writer's attention at these times of high water. Along with other machinery sent by the contractor for the carrying on of this work was a pulsometer pump having a capacity of about 180 gallons per minute. This pump had not been fitted up for use, due to the lack of a valve and a few feet of steam hose to make a flexible attachment to the boiler of a nearby hoisting engine; and it was only after several successive high waters had entered the cofferdams that these inexpensive, but very necessary fittings were obtained. Previous to fitting up the pulsometer the water had been removed by means of the derricks and hoisting buckets and also with diaphragm pumps. The following figures give the relative cost of handling the water by the two methods.

With dersicks 20,000 cu. ft.
@ $2.87 per 1000 " " $57.40
With pulsometer 20,000 cu. ft.
@ 27¢ per 1000 cu. ft. $ 5.40
Loss $52.00

The quantity of water in the above example, 20,000 cubic feet was approximately the amount handled with the derricks and buckets; and the above loss, $52.00, is the expense incurred through the lack of a few inexpensive fittings. Perhaps this loss can hardly be considered an important item in the building of a structure costing several thousand dollars, but it brings out the point that losses are often allowed to occur which could have been prevented by a little foresight and a small expense.

Excavation

All excavation before starting the cofferdams was done with teams and scrapers. The soil thus taken out consisted of a rather plastic red clay,

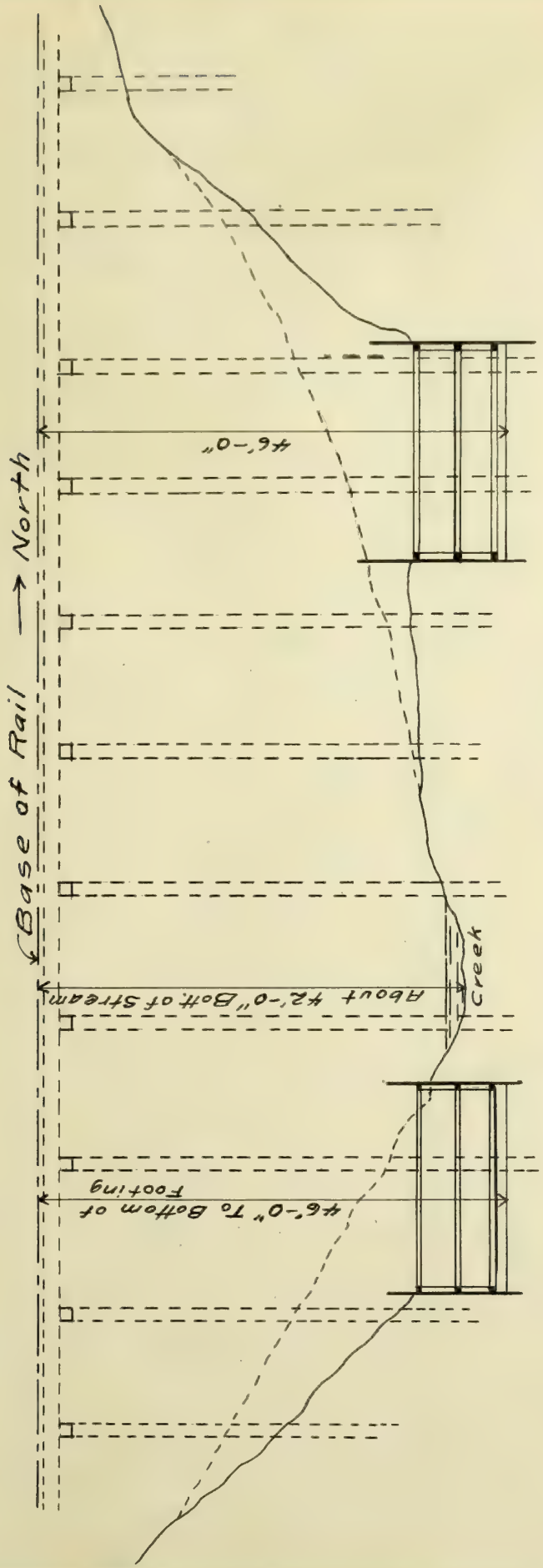


Fig. 2 Section showing cofferdam, Excavation completed.

which when the work of excavating began still held much water from the winter and spring rains; but by working a small section at a time and allowing the rest to drain out, work progressed steadily but slowly. The average length of haul was 250 feet, and an average of six teams were employed daily. All waste material was taken to the east side of the railroad embankment, either north or south of the creek, and thus helped build the embankment for the second track. The dotted line, in Fig. 2 page 10, shows the profile of the natural surface along the center line of the trestle before the excavation was started, the solid line the surface after the excavation was completed.

When the excavation was started in the south cofferdam, the material was removed by derricks and buckets. One derrick was erected immediately behind the east wing and another in front of the west wing. The derricks were worked alternately and with the same hoisting engine. Fig. 3 shows the relative position of the several parts of the work, the location of the

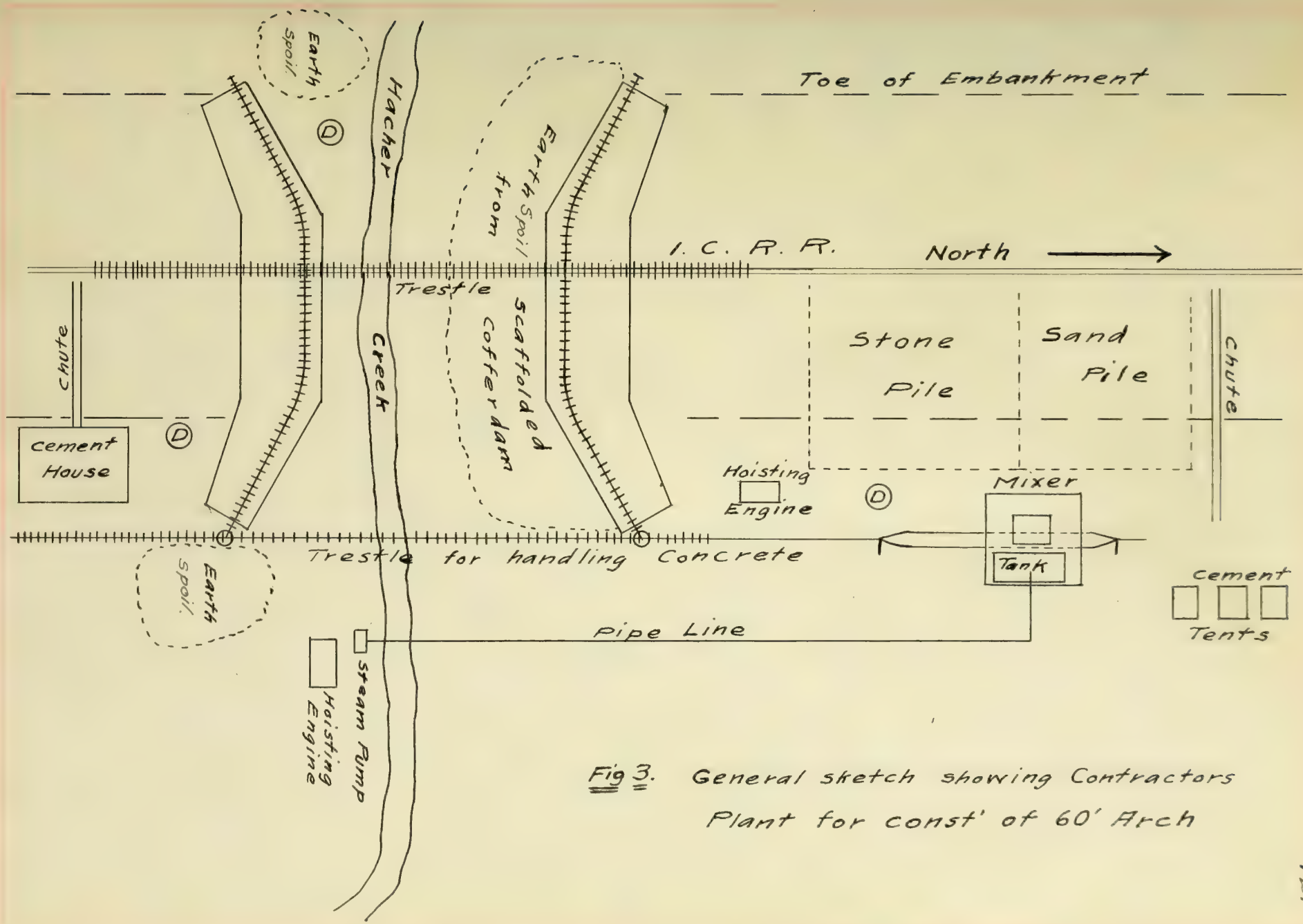


Fig 3. General sketch showing Contractors Plant for const' of 60' Arch

two derricks being marked ⓓ. The earth after being dropped by the derricks was moved further back along the embankment by the teams and scrapers as before. about a hundred cubic yards of the material from the cofferdam were left where dumped from the buckets so as to be available for filling against the back wall when the arch was completed. This back-filling, to the elevation of the launch of the arch, was included in the price for building the structure.

Before the excavation in the north cofferdam was started, a trestle had been built along the east end of the wings of both footings to carry the concrete cars, from the mixer on the north side of the creek. This trestle prevented the use of derricks and hoisting buckets in excavating the north footing, and hence scaffolding had to be used. There were two scaffolds inside the cofferdam, one above the other on each of the two frames, making three lifts before the earth reached the outside, - a very slow and expensive method of handling the material.

The necessity of scaffolding the earth from inside either cofferdam could have been prevented if the north footing had been excavated first, since then the concrete trestle need not have been built beyond the creek until after the excavation in the south cofferdam had been completed.

Cost of Excavation

As men were constantly being shifted from this job to other work being done by the same construction company, accurate data as to cost could not be obtained except from the daily destribution sheets and pay roll of the contractor; and as the writer did not have access to these accounts he can not give the exact cost of the work. However the writer kept a careful record of the number of hours each man worked and of the nature of the work, partly because of his official capacity and partly for the purpose of this record.

Following is a summary of the labor required per cubic yard for each of the three methods of handling the earth.

1. From June 4th to June 30th inclusive 635. cubic yards of earth was moved, with teams and scrapers from the north abutment, before starting the cofferdam. The expenditure of labor was as follows:

Class and Amount of Labor	Hours per Cu. Yd.
Foreman 90 Hrs.	0.160
Laborers 769 "	1.352
Teams 391 "	0.616

2. From June 4th to July 9th, 672 cubic yards of earth were moved from the south cofferdam with derricks and hoisting buckets, with a total expenditure of labor as follows:

Class and Amount of Labor		Hours per Cu. Yd.
Foreman	153 Hrs.	0.228
Engineer	143 "	0.213
Fireman	143 "	0.213
Laborers	2887 "	4.210

This does not include the cost of coal and oil, nor of the wear and tear on machinery, which could be only estimated as the hoisting engine was constantly being used for other purposes.

3. The following is an approximate estimate of the labor required in removing 560 cubic yards of earth from the north cofferdam by means of scaffolds.

Class and Amount of Labor		Hours per Cu. Yd.
Foreman	165 Hrs.	0.295
Laborers	4536 "	8.100

These values are large, but before finally being disposed of the earth was often handled five times.

The rehandling by teams and scrapers cost nearly as much as taking the earth from its native bed by the same method.

Pile Driving

The pile driver is shown in Fig. 4, page 18. The hammer was operated by a friction clutch on the hoisting engine. The engine was placed on the bed frame of the pile driver so as to move with the leaders. The movement of the machine backwards and forwards was affected by turning the rollers, and sidewise by sliding. The leaders

were 34 feet from the head block to the bottom of the bed frame, which gave the hammer a maximum fall of 28 feet. The length of the leaders was limited to 34 feet that they might pass under the pile trestle. The hammer weighed 2500 pounds and the cast-iron bonnet 770 pounds.

The instructions for pile driving required, for a 2400 pound hammer and a fall of 20 feet, a penetration for each of the last three blows of 1½ inches or less, and a total penetration of at least 18 feet. A final penetration of 1½ inches was nearly always obtained, and the total penetration average 23 feet.

The writer as inspector for the railroad company was required to record the following data concerning the pile driving: (1) number and row, indicating position in footing; (2) length; (3) diameter, butt and tip; (4) total penetration below base of rail; (5) distance from base of rail to ground; (6) penetration below ground surface; (7) distance from base of rail to bottom of footing;

(8) distance from base of rail to "cut off"; (9) total number of blows; (10) for last three blows, the hammer fall, and the penetration; (11) length of follower, if used; (12) remark column stating condition of pile after being driven. In addition at the top of each page the following records were called for; the weight of the hammer, the weight of the bonnet, the greatest depth of creek below base of rail at any point within the right of way, and the average elevation of the original ground on the center line of the footing.

Fig. 4 Veiw of Pile Driver and Dump back of South Cofferdam.

Fig. 4 shows the pile driving in progress in the south cofferdam. The driving under the trestle has been about finished, but none of the bracing between the bents has yet been replaced. In the background is the cement house and chute for unloading cement, which will be described later.

Two very heavy rains at the beginning of the pile driving had thoroughly soaked the embankment back of the south cofferdam. Partly owing to the decreased stability and partly to the continual jarring by the pile driving several large cracks opened at the top of the embankment extending to near the ends of the wings, and at the same time a large settlement of this part of the embankment took place. This threw heavy and unlooked for pressures against the sides of the cofferdam, and it appeared for a time as if the cofferdam would not be able to stand the pressure. Fortunately dry weather set in and as the cross

braces were doubled no accident occurred.

The requirements for the piles carrying the falsework and centering were a penetration of 2 inches for each of the last three blows of a hammer weighing 2400 pounds and a fall of 20 feet, and a total penetration of 15 feet. These piles were cut off 27 feet below the base of the rail or about 12 feet above the average ground surface. The expectation was that piles 35 feet long would give satisfactory results; but a test pile with a fall of 13 feet gave a total penetration of 22 feet, and a penetration for each of the last three blows of 4 inches. The contractor's foreman and the writer in the absence of the chief inspector decided that piles driven with such results could not be trusted to carry the load; and concluded to continue driving until a satisfactory penetration was obtained, and to make up the deficiency in height by building a false bent on top of the piles. Later the chief inspector approved this

plan and it was continued for all falsework piles.

Cost of Pile Driving

The following is the labor expended in preparing, driving, and cutting off the 160 piles in the south footing.

Driving

Class and Amount of Labor	Hours per Pile.
Foreman 125 Hrs.	0.78
Engineer 125 "	0.78
Fireman 125 "	0.78
Driver Hrs 680 "	4.25

Preparing for Driving and Sawing.

Class and Amount of Labor	Hours per Pile.
Foreman 20 Hrs.	0.15
Laborers 250 "	1.56

About 4450 lineal feet of second class piling was used, which would make the average length 27.8 feet.

PART II

Unloading of Material

Apparently a serious mistake was made as to the position in which the material was stored. A shed - shown in the photograph on page 18 - of a capacity of about 1000 barrels of cement was built south of the arch on the east side of the embankment. This shed was filled with cement before the work began. The sand and the crushed stone were piled north of the work, also on the east side of the embankment. The relative positions of the material is shown is shown in Fig. 3. This arrangement proved to be very inconvenient, as the cement had to be moved about 250 feet before being used. To move the cement it was necessary to stop the concrete mixer, in order that the cars used for handling the concrete could be used to haul the cement. Since there was more room on the railroad right away for the storage of the material

north of the creek than south of it, it seems peculiar that the cement house was not located on the south side near the sand and the crushed stone. Later three small tents were put up near the sand pile, in which the cement was stored instead of placing it in the cement house.

To facilitate the unloading of the cement a chute was built from the cement house up the side of the embankment to the track, the last section of the chute being removable to give the necessary clearance for the passage of engines and cars. A car of cement was stopped on the track opposite the chute, the removable section of the latter was put through the car door, and the sacks of cement were dropped into it. At the lower end of the chute the men caught the sacks and piled them in the house.

The sand and crushed stone were shoveled from the cars while standing on the track, and were allowed to roll down the side of the embankment. At the toe of the dump, boards

were laid to shovel from when the material was later to be re-handled. After a considerable amount of stone had been unloaded, it became impossible for the workmen, in shoveling from the cars, to throw the material far enough out so that it would roll down the side of the dump; consequently it became necessary to handle the stone again. It was thought this rehandling could be done while the work train "went in the clear"; but the time was never sufficient, and the men were occupied in shoveling the stone down the dump when they ought to have been in the cars unloading. To prevent these delays the foreman attached a scraper to the cable from one of the hoisting engines, which could easily accomplish the work of a dozen men. By passing the cable over a pulley at the bottom of the embankment, the pull was brought at right angles to the face of the stone pile The scraper after being pulled down by the cable, was dragged up the face of the dump by a couple of men pulling on a rope.

Handling and Making the Concrete

The cars used for handling the concrete is shown in Fig. 6, page 26, at about the middle of the trestle. To better explain the difficulty that arose from using these cars a sketch representing an end view and giving the main details of its construction is shown in Fig. 5.

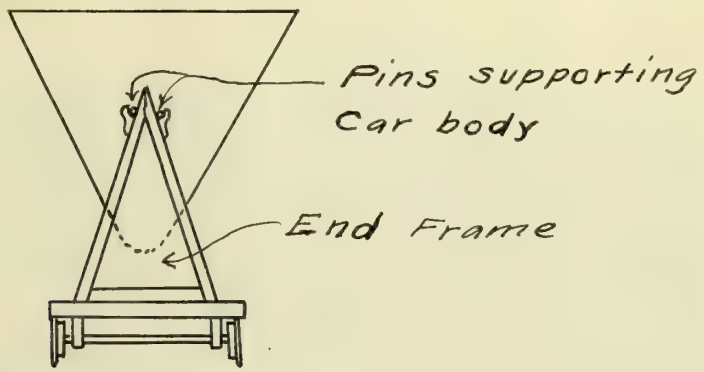


Fig. 5 Concrete Car

The triangular car body held about a cubic yard. To empty the car a couple of men at each end would put a crow bar under one of the pins and tilt the body of the car until the material slipped out. The trestle and track over which these cars moved need but a few words of explanation as they are very well shown in Fig. 6. By closely observing

Fig. 6 it can be seen that the posts carrying the trestle over the footing were set outside of the sheeting of the south cofferdam and did not interfere with building the forms inside the latter. To pass from the trestle running to the mixer to that over the footing, the cars were run upon a turn-table at the junction of the trestles and turned in the proper direction.

Fig. 6. View of Work looking South.

The hoisting engine seen at the left hand margin of Fig. 6, operated the derrick used in feeding the mixer; and the engine

across the creek back of the trestle moved the concrete cars. The mound of earth just north of the creek is spoil scaffolded from the the north cofferdam

The cars were operated from the mixer to the turn-table by a cable which was taken in by one drum of the hoisting engine while being given out by the other; to change the direction of the motion, the operation of the two drums was reversed. West from the turn-table the track was slightly inclined and the cars were operated by the men who unloaded them.

Four serious difficulties developed in this method of handling the concrete.

1. Only two cars could be used; and since it took from 4 to 7 minutes to make a trip with a car, the mixer was often delayed.

2. The turn-table due to its rude construction was slow and required too many men to operate.

3. The car was very hard to empty, four men with pry bars finding it

at times difficult to tilt the body of the car sufficiently to make the concrete slide out. This was due to the pins which carried the car body being set too far apart.

4. With so large a quantity of concrete being dumped from 12 to 16 feet into the forms, there was always danger of spreading the latter. This large quantity when put in at once, also made it impossible to do satisfactory facing. More men were always required to level and tamp the concrete then could work to advantage.

However, regardless of these difficulties, the method described was continued until the concrete had about reached the track, or about the elevation of the haunch of the arch.

A method previously suggested, but not then approved of, was now adopted for placing the remaining concrete. This consisted in lowering the track until it was slightly inclined downward away from the mixer, and also chang-

ing it to run close to the east end of the north abutment and curving west nearly to the center of the arch. This track and new trestle is shown in Fig. 7. Above the extradoes of the arch a platform was erected resting on posts which in turn were supported by the falsework caps. On this platform a derrick,

Fig. 7. Veiw showing Forms.

having a mast 45 feet high and a boom 50 feet long was placed. This derrick was able to take the concrete bucket from the cars standing on the end of the track and dump them into nearly any of the forms.

The body was taken off the concrete cars, and platforms large enough to hold two ½ yard hoisting buckets were built on the trucks. Two men pushed the loaded car down the incline from the mixer and also the empty cars back.

By using two flatcars and five buckets the mixer was never delayed. The derrick being able to lower the buckets to any desired depth did away with any danger of the forms spreading; and the concrete being handle in smaller units was easier taken care of.

The following data still further brings out the advantage of the second method over the first.

Distribution Sheet

Item	Method	
	1st	2nd
Foreman	1	1
Hoist. Engineer	2	2
Firemen	2	2
Stone Shovelers	5	5
Sand "	2	2
Cement Carriers	1	1
Laborers handling dump box	2	2
Mixer Attendants	2	2
Signal men	1	1

Box Dumpers	2	2
Switchmen	1	—
Car Handlers	2	2
Car Dumpers	4	2
Form Men	6	4
Water Boys	2	2
Total Labor	35	30
Total Output	100 cu. yds	120 cu. yds.

The Smith's No. 2 mixer - one of the double cone type - was placed on a framework high enough for the cars to pass under it, which allowed the contents of the mixer to be dumped directly into the cars. Fig. 8, page 32, shows the mixing plant with one of the cars in position under the mixer and with a box loaded with material, just ready to be lowered and dumped into the chute above the mixer. This chute opened into the mixer through a trap door in the bottom. On the mixer platform, in Fig. 8, will be noticed a tank which furnished water for the mixer, for cooling the gasoline engine operating the mixer,

for the hoisting engine, and also for wetting the stone pile. The water was pumped from the creek to this tank by a small direct-acting steam pump.

Fig. 8. View of Mixing Plant.

The box used for lifting the materials from their respective piles to the mixer was divided into two compartments, each of which emptied through a door in the end of the box. This door was hung at the top and swung outwards, but was held by a catch which was tripped when it was desired to dump the contents of the box. In

handling the material the method of procedure was as follows: The box was first placed at the sand pile and the compartment intended for sand filled. When the derrick returned with the next empty box, the one already filled was picked up and moved to the stone pile. Here the compartment for stone was filled and the proper proportion of cement in bags was placed on top of the stone, while the derrick made another round trip. On returning from the sand pile the derrick seized the box at the stone pile and swung it to the mixer platform where the material was dumped into a hopper, after which the box was again returned to the sand pile.

Arch Centers

The arch centers consisted of three half polygons whose sides were about 3 feet 6 inches long and were made of 2"x10" planks which were bolted together with 5/8" bolts. The segments of the two outer polygons broke joints, while the segments of the center polygon above the horizontal chord

acted as fillers between the radial posts, below this chord they broke joints.

The pressure of the concrete on the arch centering was carried to the false-work by the radial posts whose lower ends rested on 8"x8" timbers. The vertical component of this thrust is taken by the 8"x8" timbers, while the horizontal thrust by the horizontal chord. This horizontal chord consisted of two 2"x10" planks bolted one on each side of the foot of the radial posts, and a third 2"x10" plank cut to fit snugly between the posts and spiked on top of the other two planks thus forming an inverted trough. In the upper end of the radial posts was cut a 2 inch tenon to fit between the segments of the two outer polygons, which thus rested on the shoulders made on either side of the posts.

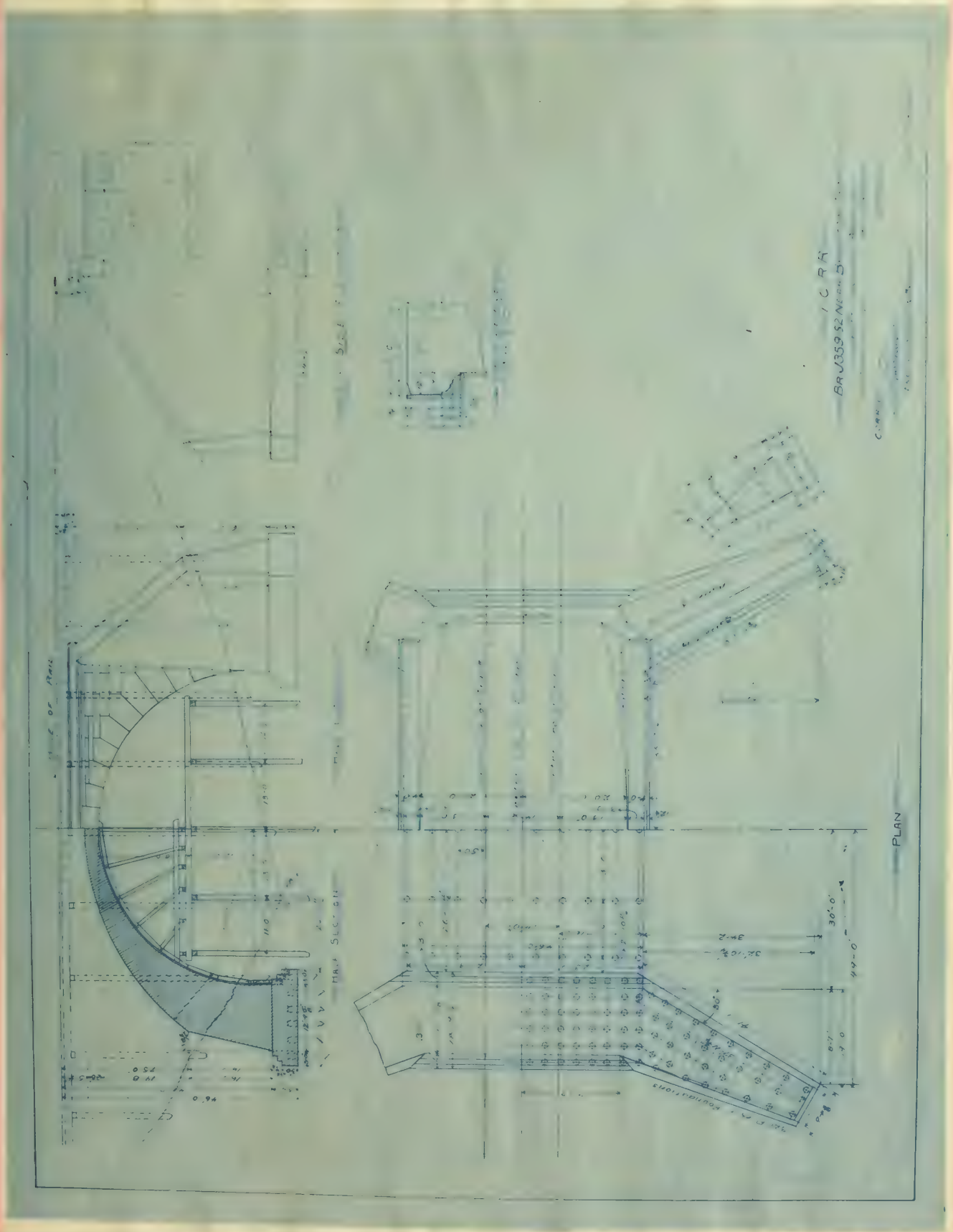
The length of the arch, 46 feet, was divided into twelve approximately equal spaces of 3 feet 10 inches each. The allowable spacing of the centers for 3-inch lagging was 4 feet. This gave an opportunity for varying

the spacing of the centering under the pile trestle where it was sometimes necessary to shift a line of centers to avoid one or more of the piles. The lagging consisted of 3"x10" planks dressed on both sides and was "toe nailed" to the centers.

The segments for the centering were made at the sawmill and according to templates sent by the contractor. Only two sizes of segments were needed — those for the outer polygons and those to act as fillers between the posts. The posts were cut and sized by the contractor's carpenters on the spot. To obtain the length of each post and the angle at which the tenon was to be cut, the plan — see page 36 — of the centering was drawn to full scale on a board platform. This platform is shown in Fig. 9, page 38, with the men busily engaged in laying out the work.

It had first been decided to put the centering together on the platform on which the plan for the same had already been

Plan of Arch.



laid out, from there to build a runway to the arch over which the centers could be moved on trucks; but later it was seen this would not be expedient. Instead, a platform was erected over the creek, east of the arch and immediately adjacent to the falsework and at the elevation of the top of the latter. On this platform the plan of the centering was again laid out and the arch centers built to it. When a center was finished and bolted together it was raised to a vertical position and moved horizontally to its position on the falsework. For the centers beneath the trestle the horizontal chord was first placed on the falsework and on it the position of the radial posts marked, these posts were next set and to them were bolted the segments.

Double wedges were placed under each radial post and, at the springing line under the end of the last segments. These wedges were made of oak and were soaped on both faces to facilitate driving and removal.

Fig. 9. Work Looking North

Forms.

No forms were built for the footing courses, the concrete being placed against the sheet piling. Above the footings all the concrete was built between forms. These consisted of 6"x8" studding to which were nailed 2"x8" boards. The spacing of the studding was 4 feet or less throughout. The backwalls as well as the face walls were made of tongued and grooved lumber, dressed on both sides, the best of this being selected for the exposed

surfaces and the poorer quality for faces eventually covered. As a result of thus selecting the lumber unusually tight forms and unusually smooth face walls were obtained. Although many of the studding had been ~~been~~ used once, and some twice, before and naturally would be somewhat bent, yet by taking care to place the bend in a direction parallel to the face rather than perpendicular to it, and by exercising care at all times, excellent results were obtained. Due credit for the exellent construction of the forms should be given to the contractor's foreman - a very capable and experienced man.

No trouble was experienced from the water in the concrete draining of through cracks in the forms and carrying with it the cement, although the concrete was mixed unusually wet.

The bottom of each studding was held against outward pressure by a block placed between it and the sheet piling. At the height of about 8 feet shores ran from the posts to the ground. This was the

greatest height at which it was possible to use shores reaching to the ground as braces, for the front face walls. Above this height, the front and back walls were tied together with iron rods running through the forms. The backs walls could, however, still be braced against the embankment, as the latter rose very abruptly back of the work. The rods used to hold the front face in place, were placed in tiers about six feet apart. These rods did not pass through the studding but through a waling piece laid against the former. Fig. 10 shows the manner in which these rods were used; this of course was applicable only in the wing walls where the two faces were not far apart.

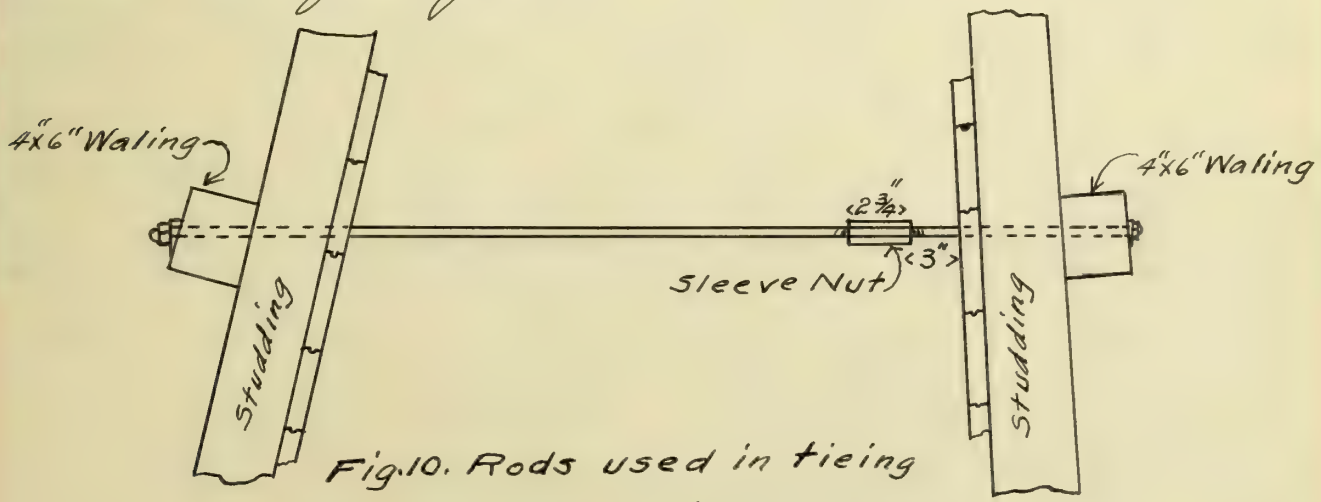


Fig. 10. Rods used in tieing the Face Wall to the Back Wall.

A different method was used in bracing the face walls of the arch ring, which will be explained later.

After the wings had been built and the forms taken down, the short piece of rod on the front face was screwed out of the sleeve nut and the hole filled with neat cement mortar; on the back the projecting ends of the rods were broken off as near the face of the wall as possible, and any concrete knocked loose was replaced with mortar.

The face markings shown in the plan, to give the concrete work the appearance of stone masonry, were obtained by nailing triangular strips on the face forms. Care was taken to get a sufficient coat of mortar over these V strips so that the concrete stone would not be exposed.

It is usual in building an arch ring, not constructed in voissoirs, to place the two face sections first, and later build the inner arch sections. Proceeding thus it is often a difficult matter to provide bracing strong enough to keep the face

walls from spreading at the top. The method of bracing most used is to let every third or fourth piece of lagging extend from 2 to 3 feet beyond the face of the arch, and then from the end of these lagging pieces to insert inclined struts to brace the studding. Owing to the small angle these struts make with the studding and also to the bending of the lagging, this is a very unsatisfactory method. When building the section next to the face section, loops of wire were anchored in the concrete and allowed to protrude a few inches — see Fig. 10. Into these loops adjustable rods, similar to those used in the wing walls except for a loop in one end instead of threads and a nut, were hooked. The foot of the studding was rigidly held in place by blocks bolted to the lagging. Any movement that occurred at the top due to the stretching of the wires could be taken up with the sleeve nut. As far as the writer's knowledge extends this method of building the arch ring has never been tried before; but it was very successful

and could well be adopted by others.

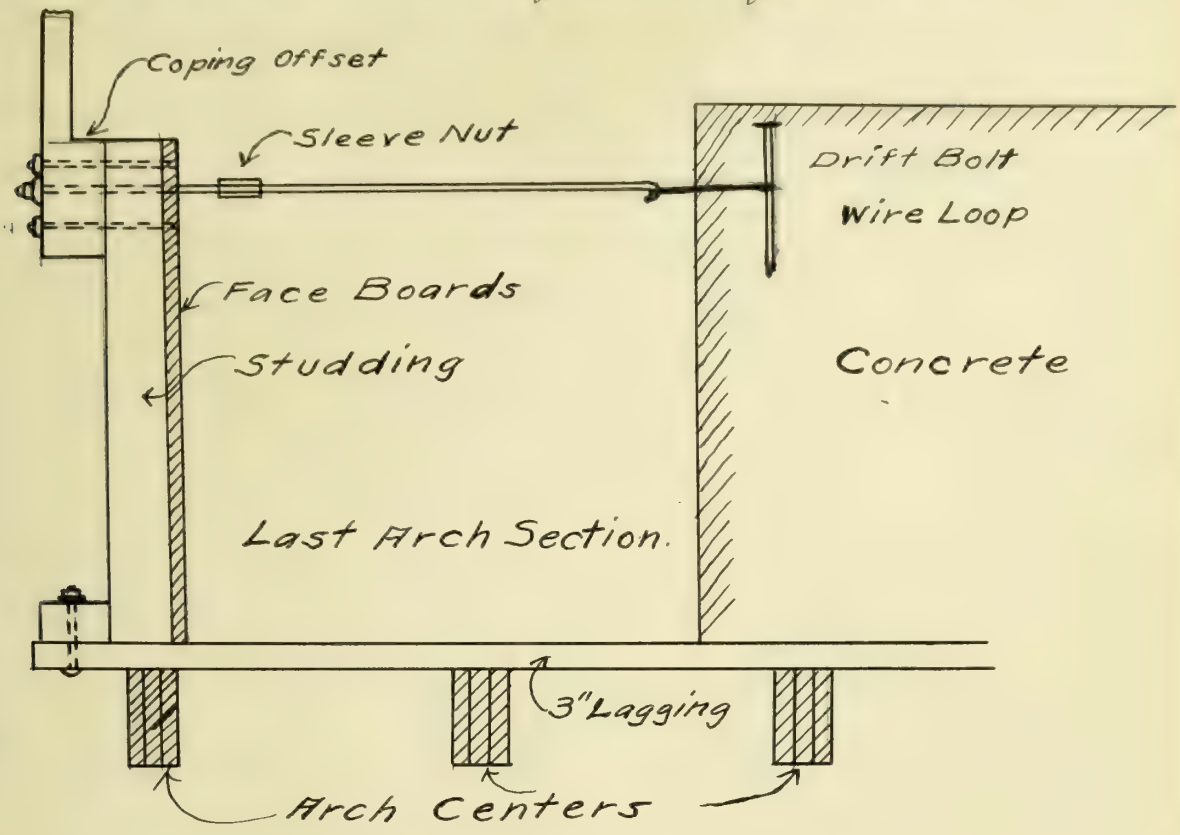


Fig. 12. Section Through Top of Arch Ring Showing Face Form and Rods.

Concrete Mixtures

The 5-foot footing courses consisted of concrete made of 1 part of cement 3 parts of sand and 6 parts of crushed stone; and the 3-foot bench walls, the wings, and the retaining walls above the arch ring were made of a 1:2½:6 mixture. The arch ring above the springing lines alone was made of 1:2:5

concrete. All proportioning was done by loose measurements, sometimes the cement was measured in boxes as well as the sand and crushed stone; but more often the sack of cement was taken as the unit, and the sand and crushed stone were proportioned accordingly. The facing mortar consisted of 1 part of cement to 2 parts of sand and was mixed only in such quantities as could be used inside of an hour from the time of mixing.

The total amount of concrete involved was 3200 cubic yards. By comparing the yardage with the time consumed in the erection it will be seen that progress was not very rapid. There was, however, no demand for the arch to be finished quickly, and as the work could be done more cheaply when progress was less rapid plenty of time was allowed for the completion. At the time of finishing this description – May 17th 1907 – the structure is in use, presenting a good appearance and appearing to be in every way satisfactory.

The contracting firm, which built the

bridge, was the Bates and Rogers Construction Company of Chicago, Illinois. The work was carried on under the direction of Mr. H. H. Hadsall. Assistant Engineer with the writer as resident inspector.

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